§2. Sub-Ignition in FFHR Based on Recent LHD Experiments

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Physics performance should be predicted for FFHR helical reactor based on LHD experiments showing H-mode like behaviors with the confinement factor of 1.5 over the ISS95 scaling without L-H transition.[1]

The comprehensive feedback control method developed for ignition access in ITER[2] can also provide the control algorithm for FFHR. Here, the heating power P_{EXT} is controlled by the H-mode power threshold to keep the H-mode and the fueling rate is controlled by the fusion power P_f to keep it at the desired values. However, as the clear L to H transition has not been observed in LHD experiments, we should explore the alternative control algorithm for the heating power. In this report we propose the control algorithm for the heating power based on the density limit scaling[3] with the power balance as a simple control tool.

The heating power is applied so as to keep the density within the limit. The operating point can access the sub-ignition point keeping off the density limit regime. Hence, the heating power is given by

$$P_{EXT}(DL)\,[W] = \left(\frac{\gamma_{DL0} n(0)\,[m^{-3}]}{\gamma_{pr} 0.25\times10^{20}}\right)^2 \frac{R\,a^2}{B_o[T]} \times10^6 - (P_\alpha - P_B - P_S)$$

where γ_{DLo} is the set value of the density limit factor (=1.1), γ_{pr} is the profile factor, n(0) is the peak density, B_o is the magnetic field strength, P_α is the total alpha heating power density, P_B is the total bremsstrahlung loss, and P_S is the total synchrotron radiation loss.

The temporal evolution of plasma parameters during the sub-ignition access is shown in Fig. 1 for B_o= 10 T, γ_H = 1.6. When the preprogrammed heating power of 30 MW is initially applied for 5 sec, the temperature quickly increases up to ~20 keV and then decreased to ~13 keV. After feedback control is switched on at 5 sec, the heating power quickly increases with the density and reaches the maximum heating power of 100 MW. The density limit indicator $\gamma_{DL} = n(0)_{limit}/n(0)$ is initially as high as 2.2, and then decreased to 1.2 after saturation of the heating power. Thus we see that the density is always less than the limit. Fueling feedback control with proportional-integral (PI) is switched on at 5 sec, and then the electron density linearly increases to obtain the desired fusion power and reaches 4.2×10^{20} m^{-3}. The alpha ash fraction reaches 2.1 %, the beta value up to ~1.6 %, and the neutron wall loading up to 1.8 MW/m^2. Q= P_f/P_{EXT} =10 is obtained in FFHR.

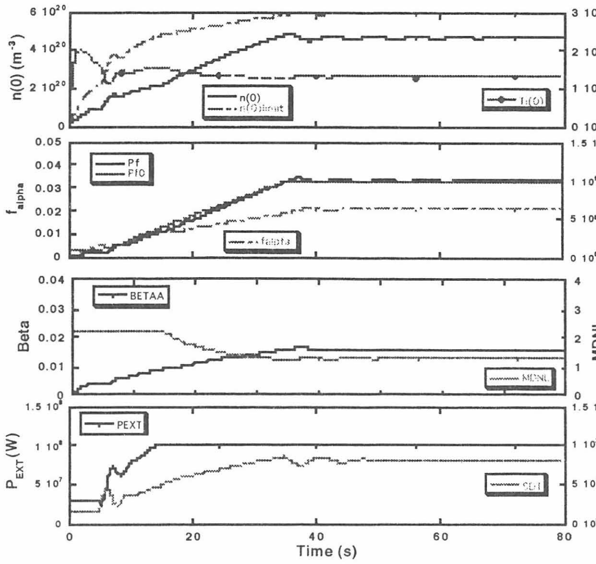

Fig. 1 Temporal evolution of plasma parameters during the sub-ignition access phase with a PI fueling feedback control in FFHR.

Table 1. Machine and plasma parameters for the small size of FFHR.

Major radius:	R = 10 m
Minor radius:	a = 1.0 m
Magnetic field:	B_o= 10 T
Fusion power:	P_f = 1 GW
Maximum external heating power:	P_{EXT} = 100 MW
Enhancement factor over ISS95 scaling :	γ_H = 1.6
Neutron wall loading:	Γ_n = 1.8 MW/m^2
Alpha particle density fraction:	f_α= 2.1 %
Oxgyn impurity fraction:	f_O = 0.5 %
Effective charge:	Z_{eff} = 1.32
Alpha confinement time ratio:	τ_α^*/τ_E = 3
Temperature ratio:	T_i/T_e = 1
Fuel ratio:	n_D/n_T = 1
Alpha particle heating efficiency:	η_α = 0.7
Wall reflectivity:	R_{eff} = 0.9
Hole fraction:	f_H = 0.1
Density profile:	α_n = 1.0
Temperature profile:	α_T = 1.0

References

(1) O.Motojima, et al., Physics of Plasma, 6 (1999) 1843.
(2) O. Mitarai and K. Muraoka., Nuclear Fusion, 39 (1999) 725.
(3) S. Sudo, et al., Nucl. Fusion, 30 (1990) 11.